Connectivity directionally-encoded color map: a streamline-based color mapping

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Submission Number:

556

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Introduction:

Diffusion-weighted (DW) magnetic resonance imaging (MRI) and tractography are used to reconstruct white matter (WM) pathways between brain regions. A growing number of studies exploit structural properties of these pathways or streamlines to infer structural connectivity between areas (Hagmann et al., 2008, Pannek et al., 2011, Fornito et al., 2013). Thus, it is of interest to develop new tools to visualize these properties. In a similar fashion as in (Calamante et al., 2012, Pannek et al., 2011), we are interested in the properties of streamlines intersecting a three dimensional grid. In (Calamante et al., 2012) the authors proposed the method directionally-encoded color Track-Weighted Imaging (DEC-TWI) which represents the average orientations of segments of streamlines going through each voxel. In (Pannek et al., 2011), the authors proposed the method Average Pathlength Map (APM), that generates a scalar map of the average length of streamlines intersecting each voxel. In this study, we propose a novel orientation color-coded map based on streamline tractography.

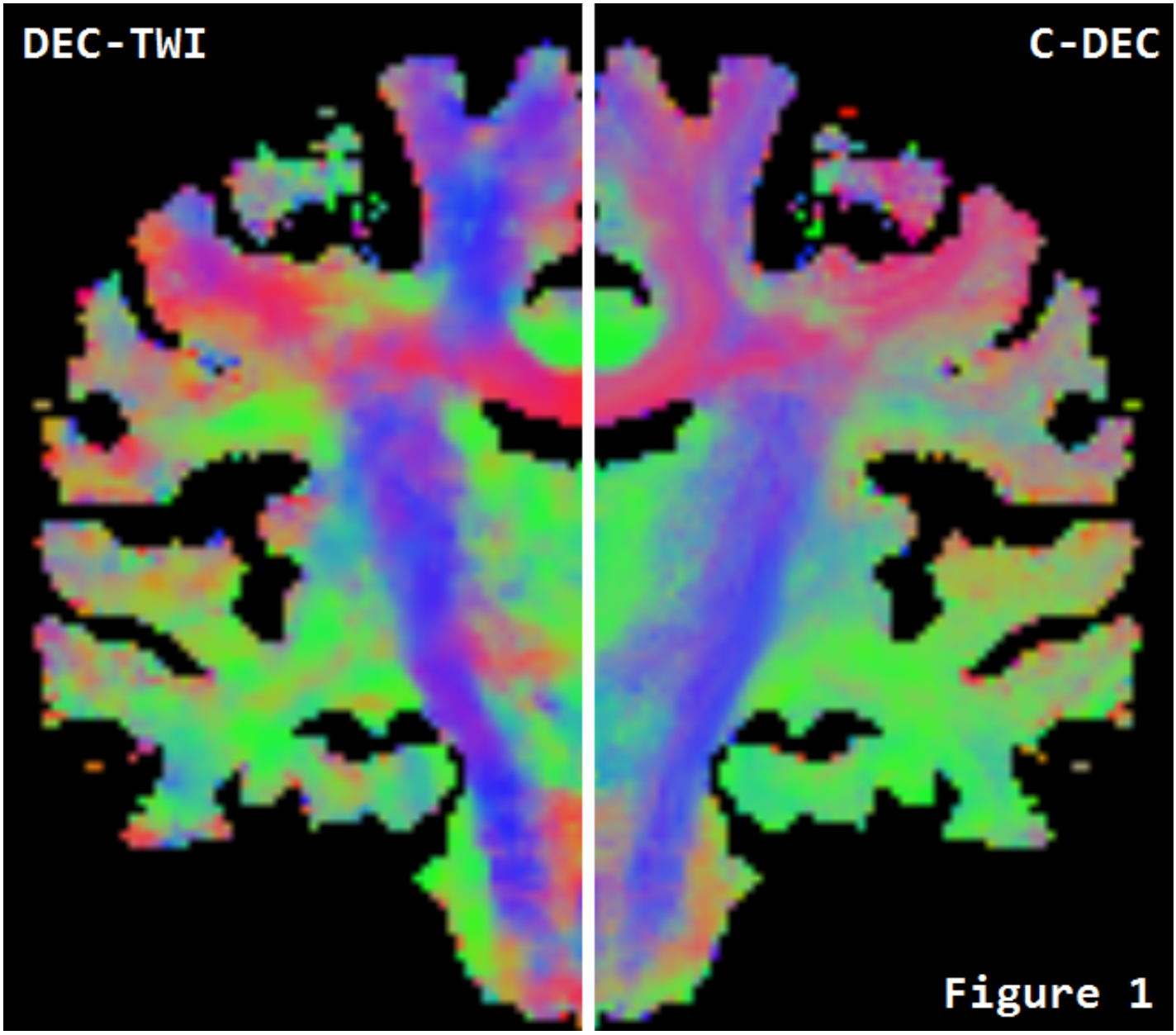
Methods:

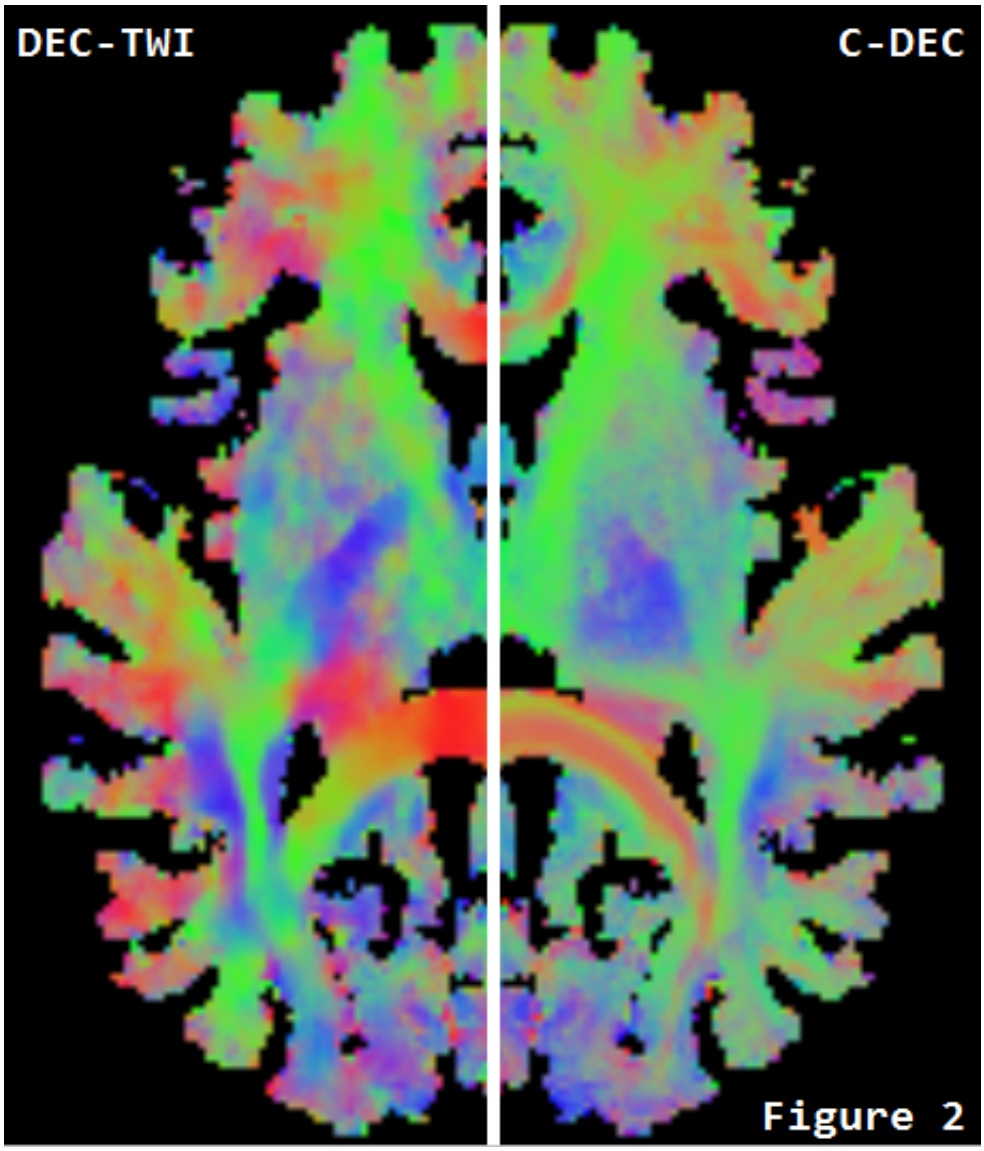
We propose the method Connectivity directionally-encoded color (C-DEC) map, which maps the average orientation of streamlines going through each voxel. We define the orientation of a streamline as the absolute value of the unit length vector connecting both extremities. For every streamline intersecting each voxel, the average orientation vector is taken (the normalized sum of the orientation of all vectors). The length of the segment of a streamline intersecting the boundaries a voxel depends on the position of the streamline and the voxel. In this study, we weighted the contribution of each streamline orientation to the average orientation by the length of the segment of the streamline in the voxel. In a similar fashion, we generated the DEC-TWI map, averaging the orientation of segments of streamlines intersecting the voxel. Thus, DEC-TWI is a map of the local structure orientation in the voxel and C-DEC is a map of the 'global' structure orientation going through the voxel, both estimated from streamline tractography. The color-coding of the average orientation is the standard red-green-blue convention (red: left–right, green: anterior–posterior, blue: inferior–superior) (Calamante et al., 2012, Pajevic et al., 1999).

DW images were acquired on a single volunteer along 64 uniformly distributed directions using a b-value of b=1000 s/mm^2 and a single b=0 s/mm^2 image using the single-shot echo-planar imaging sequence on a 1.5 Tesla SIEMENS Magnetom. An anatomical T1-weighted 1mm isotropic MPRAGE image was also acquired. Fiber Orientation Distribution Functions (fODFs) reconstruction were done using Mrtrix (Tournier et al., 2012) with spherical harmonics of order 8. Deterministic streamline tractography was done using the in-house algorithm described in (Girard and Descoteaux, 2012), seeding from the WM gray matter interface and using the particle filtering tractography algorithm (Girard and Descoteaux, 2012). All reconstructed streamlines have a length greater than 10mm and end in gray matter regions, ensuring that incomplete streamlines do not bias the orientation estimation.

Results:

Figures 1 and 2 show DEC-TWI maps on the left side and C-DEC mirror maps on the right side at a resolution of 1mm isotropic. Some WM bundle can be more easily identified and distinguished on the images on the right. For instance, in Figure 1, we can follow the corpus callosum (red) and cortical spinal tract (blue) while they merge near the cortex. Figure 2 shows the splenium of the corpus callosum (red) merging with the optic radiation (green).





Conclusions:

We provided a novel method to map streamlines in a color image, which can be generated from any set of streamlines. We think Connectivity directionally-encoded color maps can improve connectivity analysis by helping with streamlines visualization and WM bundles identification.

Neuroanatomy:

White Matter Anatomy, Fiber Pathways and Connectivity

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